General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

JPL NO. 9950-848

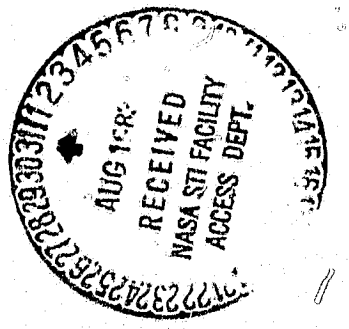
DRL NO. 191/DRD NO.SE5
Line Item No.7

DOE/JPL-956369-83/01
Distribution Category UC-63

MICROCRYSTALLINE SILICON GROWTH FOR HETEROJUNCTION SOLAR CELLS

FIRST QUARTERLY REPORT

For Period Covering
1 November 1982 to 31 March 1983



By:

P.A. Iles and D.C. Leung

and

P.H. Fang
Boston College

JPL Contract No. 956369

APPLIED SOLAR ENERGY CORPORATION
15251 E. Don Julian Road
City Of Industry, California 91746

DRL NO. 191/DRD NO.SE5
Line Item No.7

DOE/JPL-956369-83/01
Distribution Category UC-63

MICROCRYSTALLINE SILICON GROWTH FOR HETEROJUNCTION SOLAR CELLS

FIRST QUARTERLY REPORT

For Period Covering
1 November 1982 to 31 March 1983

By:

P.A. Iles and D.C. Leung

and

P.H. Fang
Boston College

JPL Contract No. 956369

APPLIED SOLAR ENERGY CORPORATION
15251 E. Don Julian Road
City Of Industry, California 91746

ABSTRACT

A total of sixteen runs of e-beam vaccum deposition of p-type microcrystalline Si (m-Si) films were attempted on n-type or p-n junction single crystalline Si (C-Si) substrates. The m-Si film thickness varied from .15 to .7um and metal contacts were deposited after plasma hydrogenation. The p-m-Si on n-c-Si structure had a Voc of up to 490mV while no Voc improvements were observed in the p-m-Si on p-n C-Si structure against p-n controls. Both CFF and Jsc were lower than control. Possible problem areas were interfaced between m-Si and C-si and the back contacts due to lack of sintering for fear of dehydrogenation.

Some methods of improvement in these areas are outlined.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The objective of this program is to exploit the utility of microcrystal silicon (m-si) for solar cell applications. Under a certain preparation procedure, this m-si has been found to have a dominant optical band gap of 1.7 eV. Hence a possible application of this material is either as a component of the heterojunction of a silicon substrate of opposite type of conduction, or as a window of a junction solar cell, thereby to improve the solar cell performance. Figure 1 demonstrates the two possible structures.

This program is a joint venture of ASEC and Boston College. The role of Boston College is to deposit and hydrogenate m-Si films on samples and to analyze the films. The role of ASEC is to prepare samples and to fabricate and test cells after m-Si films are deposited on the samples.

In the following sections, the current understanding of m-Si fabrication procedures and results of the first sixteen runs will be presented.

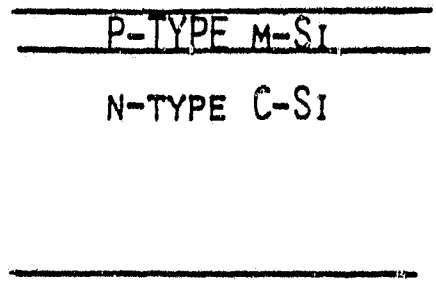
II. CURRENT STATUS OF m-Si

During the last few years, there is a rapid growth of interest on m-Si. This growth is reflected in the forthcoming Tenth International Conference on Amorphous and Liquid Semiconductors (Aug. 1983, Tokyo) where microcrystals will form a topic of the conference. Boston College has been studying polycrystalline silicon since the early seventies. Various methods of deposition have been studied initially, including the electron beam vaporization in vacuum. By a comparison of these methods, work has been concentrated on the electron beam evaporation method. (Ater several years experience.) In most of the experiments, steel coated with either silicon oxide or titanium was used as

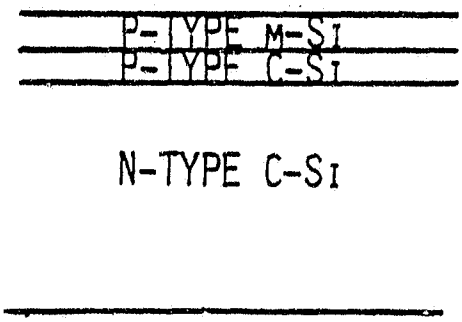
FIGURE 1

THE TWO TYPES OF STRUCTURE OF THIS PROGRAM

1) HETEROJUNCTION



2) HETEROFACE



substrate.[1] The resulting film of several microns thick shows, at a sufficiently high substrate temperature, an x-ray diffraction pattern of polycrystal silicon. Under optical microscopy, gross grains of several microns in cross-section have been observed. Later study under scanning electron microscope with high magnificantion proves that these grains actually consist of plumose crystals of about 0.1 micron in cross-section. A correlated photovoltaic study shows that better photovoltaic performance is obtained from films without a distinct grainy appearance where the plumose structure becomes obscure. An x-ray determination indicates that these crystals have sizes of several hundred angstroms. Another interesting observation is that solar cells made of this material are improved by a hydrogenation treatment, very similar to the behavior of the solar cells made of amorphous silicon (a-Si).[2] Based on those results, a paper was published with a title of submicron polycrystal silicon solar cells.[3]

In the meantime, many papers began to appear, principally by Japanese scientists engaged in a-Si research: by increasing the rf power in silane glow discharge, silicon crystalets mixed with a-Si are obtained[4] and the crystalline phase is referred to as microcrystals in spite of the fact that the size is actually much less than one micron in dimension. In the current usage, this concise work, microcrystal is adapted instead of an accurate, but cumbersome submicrocrystal as suggested originally.

In the following, some properties of m-Si pertinent to the present program will be reviewed and discussed.

1. Methods Of Preparing m-Si. A discussion of different preparation methods is important because of the different properties obtained depending on the preparation methods. There are three methods presently studied:

   i. Glow discharge of silane, similar to the process to prepare a-si, but at a higher rf power.[4-5]

   ii. Chemical transport between a solid silicon charge and the substrate, all in a hydrogen plasma.[7,8]

   iii. Electron beam evaporation of solid silicon in vacuum at a substrate temperature above 500°C.[3,9]

The size of these microcrystals is variable but generally is in the order of 100A. This size can be modulated by the change of deposition parameters available in different preparation methods.

2. Optical Absorption Spectrum. The wavelength dependence of the absorption coefficient is shown in Figure 2. The main part of this figure is a reproduction from the reference 8, superimposed on which are the data from glow discharge and electron beam evaporation. The data from glow discharge are available only in a limited photon energy region[5] and are reproduced as a shaded area with upper edge for lower rf power and the lower edge higher rf power. The data from electron beam evaporation are closer to those of glow discharge than those of chemical transport.

In the $(\ )^{1/2}$ vs hv plot, the chemical transport case gives an optical band gap of 1.1 eV, closer to that of single crystal. On the other hand, the optical band gap values from both glow discharge and e-beam evaporation are very similar, both give 1.7eV. An interpretation of this 1.7 eV gap as a

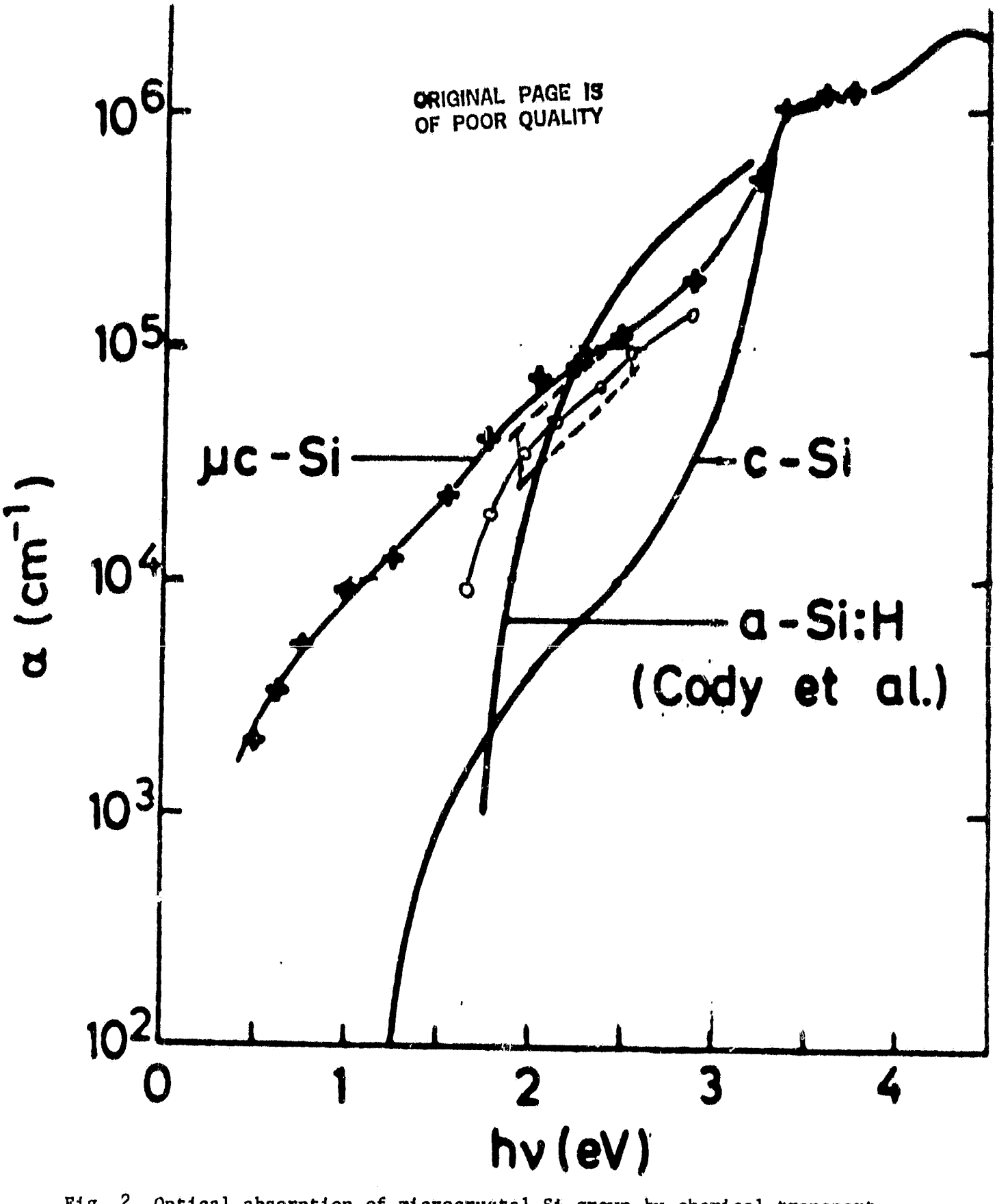


Fig. 2 Optical absorption of microcrystal Si grown by chemical transport (// c-si). Vacuum evaporation (0) and high rf power glow discharge (---). For comparison, amorphous Si:H and crystalline Si also are shown.

manifestation of the second indirect transition of silicon has been presented elsewhere.[11]

There are two points to be observed in the absorption spectrum away from 1.7eV: the mixing effect of m-Si with a-si and the relation between m-Si with single crystal silicon (c-Si). As shown in Figure 1, there is a transition energy below which of m-Si is higher than that of a-Si and above this transition energy vice versa. The value of this transition energy, about 2 eV, is an important region of photon abundance in the solar spectrum and in this respect, m-Si has a more desirable property than a-Si for photovoltaic applications. (2) in comparison with c-Si, in spite of the existence of a prominently higher band gap of 1.7 eV, has a tail in the low photon energy region which is higher than that of single crystals and presumably also that of large grain polycrystals. Therefore, an m-Si solar cell can be made thinner than c-Si but still produce the same number of electron hole pairs.[3]

3. Doping Effectiveness. Similar to a-Si, m-Si can be doped by the same impurities as those used in the doping of c-Si, but there is a quantitative difference: the effectiveness of a dopant in the host material is described by the ratio of ionized dopant to the total dopant concentration which includes besides the ionized, those not ionized either because of the thermodynamical distribution for a given ionization energy, or because the impurity is located near lattice or electrical defects. Denoting by C the impurity concentration to produce a desired electrical conductivity, it was reported that $C_a/C_m \quad C_m/C_c \quad 10^3$ as a first order approximation[12]. When taking the difference of the carrier mobiity of these three states, a-, m- and c-, into account, these values of 10^3 would be somewhat smaller. One

benefit of the good effectiveness of doping impurity is the high electrical conductivity and consequently when devices are made with an electrode contact through a m-Si layer, an ohmic contact can be realized more easily.

4. Transition Region For Growth Of m-Si. In most investiations of m-Si, a foreign substrate such as glass, quartz[10,13] or metal surface[9,11] is used. On the foreign substrate, the growth would be a heterogeneous system and a spontaneous growth is required. The initial growth according to these observations indicates an amorphous state and a transition region, as much as 500A before a full growth of m-Si. In the present work, single crystal silicon is the substrate, and there are three possibilities: i) an epitaxial growth of single crystal, ii) an amorphous initial state followed by m-Si, and iii) an instantaneous growth of m-Si. The consequence is important, but an isolation of the actual happening is not an easy experimental problem. The problem is important because in the present application, the thickness of m-Si is contemplated to be from 1000 to 3000A. If a transition region of 500A is involved, this interfacial state, which would have different properties from that of m-Si, would have a strong influence on the solar cell performance. One experimental approach to verify this problem is an in-situ Raman spectroscoic observation during the growth.[14] Such a complicated arrangement is beyond our scope of investigation at present.

5. Morphology Of m-Si Film. As stated in the beginning of this section, we have observed that under some conditions, a columnar growth of m-Si in specimens deposited by electron beam evaporation. A similar morphology

is also observed by a glow discharge deposition.[15] There are two interpretations of this morphology: the first is a suggestion that m-Si is surrounded by SiH_2 group which acts as a hindrance against a later growth.[16] This clearly is not applicable to our case since in our growth, there is no hydrogen involvement. The second suggestion is that there is a surrounding a-Si network forming the columnar wall.[17] In our system, we have observed that there is a narrow temperature region between 500 and 525°C where a-Si and m-Si are coexisting, but near 600°C where most of the present work is conducted, we believe that thermodynamically a-Si is no longer stable. There are other factors which control the morphology, such as the substrate temperature and the deposition rate which could modify the Si-Si network. In conclusion, the network of our system is conceivably different from the widely studied Si-H and Si-H-F systems but little is known at present.

6. Window Material. To complete this section on the present status of m-Si, we include here a reference by Uchida et al[18] which was published very shortly after our publication covering the same subject, a doped m-Si window on a-Si solar cell.[9] The principal consideration of these two works are quite similar except the structure and the method of fabrication of the solar cells. In the work of Uchida, m-Si is phosphorous doped, i.e. n-type, while ours is boron doped p-type and the method of fabrication in the case of Uchida is high rf power glow discharge. More recently, Uchida and his coworkers have developed a tandem structure with two p-i-n cells of different band gap materials with i-regions which are amorphous, but p and n regions are microcrystals. A photovoltaic conversion efficiency exceeding 10% has been reported.[19]

It will be useful to summarize first previous experience in Boston College on four types of solar cells, all made by e-beam evaporation on steel substrate and treated by a post-hydrogenation:

		PHOTOVOLTAGE(mV)	PHOTOCURRENT
1)	p-i-n (a-Si)	300	Low
2)	p-i-n (m-Si)	300	High
3)	p (m-Si)-i-n (a-Si)	500	Low
4)	p (m-Si)-p-i-n (a-Si)	630	High

In all these cells, prior to the hydrogenation, photovoltage is limited to at most a few mv. The photocurrent has been measured by a point contact without grid lines. Therefore only a qualitative description can be made.

We should add that an important step after the hydrogenation is necessary, that is, a light surface etching. Prior to the surface etching the photovoltage in type 4) cells for example, shows about 0 to 200 mV only. The role of etching could be an elimination of the shunt or the removal of the plasma radiation damage. We have not made a verification yet.

From the above results a comparison between 3), 4) and 1), 2), the effectiveness of a p (m-Si) front layer is evident among these four types of solar cells.

In this program, p-m-Si is deposited either on n-type or p-n single crystal substrate. The results will be compared with -Si results above.

III. VACUUM DEPOSITION SYSTEM AND PREPARATION PROCEDURE

The process to prepare m-Si in the present program is by an electron beam

evaporation of solid silicon in vacuum. A schematic figure of the depositioln system is shown in Figure 3. The legends are:

(0) Substrates

(1) Steel substrate holder.

(2) Heater made of ceramic plate with molybdenum resistance wire.

(3) Electromagnetic deflector for electron beam.

(4) Tungsten filament for electron emission.

(5) Titanium crucible.

(6) Intrinsic silicon crucible.

(7) p-doped silicon crucible.

(8) Boron source boat (graphite).

(9) Antimony source boat (tantalum).

(10) Shutter

(11) Thermocouple for substrate temperature measurement.

(12) Electrical lead for 2.

(13) Electrical lead for 4 and electron acceleration voltage.

(14) Water cooler for electron beam assembly.

(15) Heat shield cage with port to insert or remove substrates.

(16) Steel belljar.

(17) Plasma generating rod.

This system has been used for a number of years to make silicon thin film solar cells on steel and glass substrates. In the present program, the substrate (0) is single crystal silicon. The crystal has been cleaned by several procedures, and we have found that a convenient as well as an effective method is by a plasma cleaning. The complete procedure is detailed below.

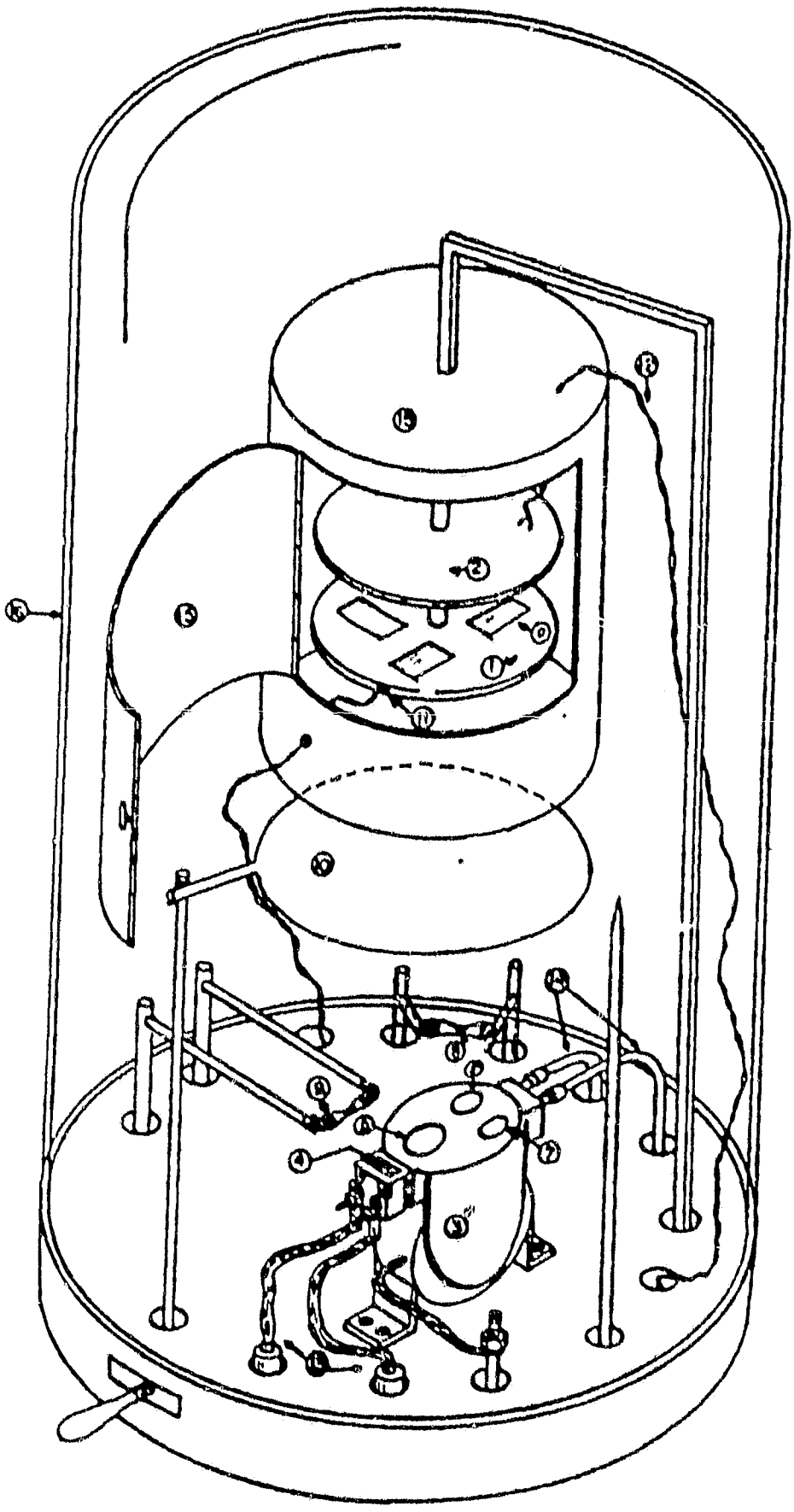


FIGURE 3
EVAPORATION ASSEMBLY

Silicon, supplied by ASEC is placed on a steel substrate holder (1). This substrate holder has five recess frames of 1x2 inch and each an opening window area of 1.5 x 4.6cm^2 for m-Si deposition. In general, in these five frames, four are used for silicon crystal and fifth normally saved for glass slides from which optical studies are made.

After the specimen is placed on (1), the part of the heat shield cage (15) is closed and the bell jar (16) is closed. After a pump down to $1x10^{-5}$ torr by mechanical and oil diffusion pump, electrical power to heater (2) is connected. The temperature is measured by a thermocouple attached to (1) near one substrate (0). There is an uncertainty on the exact value of the substrate temperature because of the radiation heat loss from the substrate surface facing downward, the heat reflection from the substrate surfaced facing upward to the heater (2), and a peripheral contact between the substrate 0 and the frame of the substrate holder (1). However, when this temperature is used as a reference temperature, the measurement can be made with a good repeatability and precision with an actual value of about 5 to 25^{o}C lower than that from the thermocouple reading.

There is some degassing during the temperature rise. After the temperature reaches an equilibrium and the vacuum reaches 10^{-5} torr again, hydrogen is leaked into the system to about 100 microns pressure and a plasma is started by a dc voltage of 3 kV with a current of about 10 ma. This plasma cleaning procedure is mostly for cleaning the oxide or silicon crystal surface and a possible residue of organic materials most of which presumably have been removed by the preceeding heating in the vacuum.

After 15 minutes of plasma treatment, the hydrogen lead is closed. Liquid nitrogen is intorudced into a Meisner trap in the system and the vacuum is reduced to 2×10^{-6} torr in about 15 minutes. m-Si deposition is then commenced.

In the present program, the required m-Si is p-doped with a sufficient dopant concentration. The dopant we use is boron which can be introduced by coevaporation of intrinsic silicon (16) and boron from a graphite boat (18). This graphite boat is a rod of 6mm diameter with a reduction in the central portion to about 4mm. In the center, a recess hole of about 2mm depth and 3mm diameter is made to receive a small boron grain. The two ends of the rod of 5cm in length are tightly wrapped with tantalum foil and are then connected to heavy electrodes. In the operation, the ac voltage is about 6 volts and the current about 120 amperes. The temperature near the hole where boron is placed is about $1800^{\circ}C$, depending on the desired dopant concentration, or more practically, the desired electrical conductivity. An in situ monitoring of boron concentration for the minute amount of boron is not possible. In practice, therefore, the electrical power for boron boat is determined empiricially by correlating with the final surface electrical conductivity.

Returning now to m-Si deposition. After the temperature monitored at the substrate holder reaches a predecided value which is in the range of 580 to $620^{\circ}C$, the deposition is commenced with a deposition rate of about 500 Angstroms per minute. The total thickness or the deposition rate is monitored by a Sloan quartz thickness monitor located from the source at the same distance as that between the substrate and the source, but maintained a distance from the cage to minimize the heat radition from the cage-heater assembly.

After the deposition is completed, the electrical power to the substrate heater is either disconnected or lowered. In the disconnected case, after about 15 minutes as the temperature is lowered to about 200°C, the system is opened and the specimen removed for post hydrogenation treatment. In the case of lowered power, when temperature has dropped to 400°C, a dc plasma of 3 kv, and 10 ma is introduced through the discharge rod (17). More recently, a discharge ring was introduced between shutter (10) and substrate holder (1), instead of the rod (17). A better plasma uniformity is obtained in this way. The pressure in the system during the plasma treatment is maintained between 120 and 100 microns. The treatment time is one hour and after that period, first, heater is disconnected and the temperature is reduced to 250°C in about five minutes, the plasma is then stopped and this in situ hydrogenation is completed. The case of hydrogenation outside the vacuum system is a pyrex tube capacitance coupled to a 13.6 Mc microwave power source. The pyrex tube is connected to a vacuum pump on the one end and a hydrogen source on the other end. The discharge power, the temperature and the pressure is about the same as the in situ dc plasma case. The result from the microwave treatment is generally better than the dc case at present.

IV. SOLAR CELL RESULTS

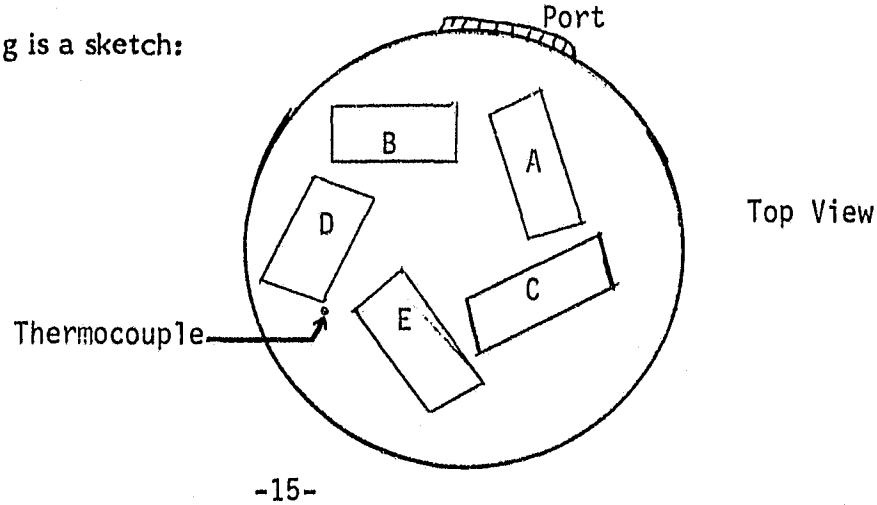
In this reporting period, a total of 16 runs were completed. 1-3 ohm-cm n-type single crystalline silicon substrates or diffused p-n junction substrates were prepared at ASEC. The wafers were polished and cleaned and in the case of p-n junction, a relatively shallow junction was diffused (2 hr. 92°C BN wafer diffusion).

The wafers were cut to 1"x 2" in size and were sent to Boston College. After m-Si films were deposited in each run a preliminary measurement of AM1 photovoltage based on metal point contact without electrodes was made at Boston College. Even though this measurement is not precise the advantage for this measurement is to evaluate the effects of hydrogenation, as well as a quick evaluation of the run. After a number of runs, samples were sent back to ASEC for cell fabrications. In each 1" x 2" sample, only an area of 4.8cm x 1.55cm was covered by the m-Si film. A number of small cells were fabricated on each sample. There were a total of three lots of samples sent to ASEC in this period. For the first lot, eight 0.7cm x 1cm cells were fabricated on each sample. For the subsequent lots, only four 1cm x 1cm cells were made on each sample. The 3rd lot included samples which had metal contacts in the back on both n-Si substrates and p-n substrates. These metal contact samples were fabricated separately from the rest of the lot. Fo all lots only low temperature (220°C) contact sintering was used to reduce the chance of dehydrogenation. Table 1 summarizes the condition of all the runs and also the resultant solar cell data. Individual cell data can be found in Appendix I.

Several explanations are to be made on Table 1.

1) The run numbers follow a chronological sequence.

2) The position indicates the substrate position on the substrate holder. Following is a sketch:



3) The blank positions in some runs are for glass or steel substrates for monitoring purpose.

4) The thickness is monitored by a shift of a quartz crystal resonance frequency in kc units of 1 kc corresponds to about 0.3 microns.

5) The value of the thickness and temperature is measured at a representative point, and a deviation of 5% from the five positions A through D is expected.

6) The value of the preliminary photovoltage is not uniform throughout each substrate, therefore, the listed value shows the a higher values.

7) For samples used in cell fabrication, the range of Voc and Jsc of resultant cells for each sample are listed alongside.

8) The * sign signifies samples with pre-deposited back contacts. Table 2 lists results of control p/n cells with the same diffusion of the p/n substrates made at ASEC for comparison.

The following observations can be made from the results.

1) For n substrates, the best Voc was obtained in runs 4,5, and 6 in Table 1 where the m-Si film is thicker (0.5um). Also appreciable improvement from hydrogenation is only observed for these runs. These results are not consistent with experience at Boston College of m-Si on a-Si cells where the optimum thickness was .05 to .1um and hydrogenation had large improvement as mentioned in Section 2. This indicates a basic difference in m-Si on a-Si and m-Si on single crystalline Si.

2) The etching step monitored in Section 2 for m-Si on -Si had no effects here for m-Si on single crystalline Si.

3) From the Appendix, the cell CFF is generally low in general. From the original I-V curves (not shown here) we could find two potential problems. One was that shunting occured in most of the samples which had Voc of 200mV or below. For the better Voc samples, some had no observable shunting, but a large curvature of I-V occurred. This indicated a interface problem between m-Si and single crystal Si.

4) The second potential problem arose because we sintered our metal contacts at low temperature (220°C) for fear of dehydrogenation. We were not sure if truly ohmic contacts were achieved in the back. That would reduce Voc even though we don't believe that this is the major reason for low Voc.

5) The motivation for predepositing a back contact before m-Si deposition was to by-pass the back contact problem. However, the m-Si deposition temperature of above 600°C for a fairly long period of time (not in H_2 or forming gas) may not be suitable for the contacts. Therefore, the results were not very consistent. The back contact was slightly discolored. However, the low voltage of some of the samples may be due more to shunting problems of the films than the back contacts. In the future, instead of predepositing metal contact, a diffused n+ back is going to be used, applied before m-Si deposition.

6) For the p-n junction substrates, so far no voltage gain over the control p/n was observed. In fact there was a voltage drop rangeing from 15mV up to more than 100mV, possibly caused by back contact effects. Of course, a drop in Jsc due to absorption in the m-Si film had an effect on the Voc too. These, however, cannot account for all the drop of Voc. In the future a p-n-n+ structure will be used.

7) SIMs study by T. Daud and K. Stika of JPl indicated high carbon contamination in some of the samples. We don't know if this has any effect on the interface properties.

From these observations, one can conclude that there is a difference between m-Si on a-Si and m-Si on single-crystal Si structure. One possible explanation of the widespread shunting in thinner films is the presence of pinholes. Also in the early runs, some improvement in Voc was observed after rehydrogenation of some completed cells. Therefore, either the first hydrogenation was not completed or dehydrogenation occured in cell fabrication (no record of preliminary Voc on those samples). However, in later runs, the preliminary Voc and the Voc of the finished cell match reasonably well and there is no strong evidence that dehydrogenation occured. However, further tests will be done in this area.

V. CONCLUSION

So far there is no voltage gain in either the hetrojunction or heteroface structures (see Figure 1) over the control diffused P/N junction cells. In the heterojunction case interface problems and possible back contact problems have limited Voc to 490mV. In the heteroface case, the solution is also not yet clear. Use of a n+ back on all the samples will eliminate the back contact problem and a better judgement can be made.

Another potential problem is the high carbon contained in the film. This should be reduced by modifying the deposition source.

TABLE 1

Run	Position	ASEC #	Type	m-Si Deposition		Photovoltage (mV)		ASEC Control Cells		
				Temperature (°C)	Thickness (kc)	Prehydro-generation	Posthydro-generation	Voc(mV) Range	Jsc(mA) Range	Lot No.
1				616	1.10					
	A	2	n							
	B									
	C	31	n							
	D	32	n					13	1.3-11.3	1
	E	1	n							
2				647	1.35					
	A	3	n					26	1.4-18.6	1
	B									
	C	33	n					30	4.4-15.1	1
	D	34	n					4	3.9-7.5	1
	E	4	n					38-107	9.5-19.0	1
3				635	2.40					
	A									
	B									
	C									
	D									
	E									
4				647	2.70					
	A	37	n			130	180	210-298	13.9-14.1	
	B	38	n			260	450	198-344	12.9-13.1	2
	C	39	n			200	486	254-460	9.8-13.3	2
	D	40	n			336	487	414-482	12.6-12.9	2
	E	42	n			168	417			
5				642	2.80					
	A	7	n			118	361	20-202	8.6-13.3	2
	B	8	n			132	471	340-426	14.3	2
	C	9	n			134	370	20-60	8.8-14.1	2
	D	10	n			133	381	402-428	148-15.1	3
	E	11	n			147	316	322-356	11.7-14.7	3

Page 2 - Table 1 cont'd.

Run	Position	ASEC #	Type	m-Si Deposition		Photovoltage (mV)		ASEC Control Cells		
				Temperature (°C)	Thickness (kc)	Prehydro-generation	Posthydro-generation	Voc(mV) Range	Jsc(mA) Range	Lot No.
6				635	2.30					
	A	43	n					376-410	14.5-14.7	3
	B	44	n					40-111	2.4-8.4	2
	C	45	n					20-414	0.8-14.3	2
	D	46	n					20-116	0.9-8.2	2
	E	47	n							
7				636	0.60					
	A									
	B									
	C									
	D	13	n			55		114-216	10.4-14.1	2
	E	46	n			135				
8				602	0.50					
	A									
	B									
	C									
	D	48	n			220	260			
	E	14	n			230	270	60-84	17.2-17.7	2
9						630	1.70			
	A	M3	n*	630	1.70					
	B									
	C	JPL	n			180		260-275	2	3
	D	M4	n*							
	E	JPL	n			180	280			
10				644	1.90					
	A	n				180		48-308	1	3
	B									
	C	JPL	n			180				
	D	M8	n*					20-80	0.5-2.4	*
	E	M7	n*					80-92	0.8-12	*

Page 3 - Table I Cont'd.

Run	Position	ASEC #	Type	m-Si Deposition		Photovoltage (mV)		ASEC Control Cells		
				Temperature (°C)	Thickness (kc)	Prehydro-generation	Posthydro-generation	Voc(mV) Range	Jsc(mA) Range	Lot No.
11				652	1.80					
	A	15	n			170	220	201-216	1.7	3
	B									
	C	50	n			120	135	20-161	1	3
	D	JPL				60	80			
	E	16	n			170		140-182	1.8-7.9	3
12				626	2.40					
	A	49	n			110		121-134	1	3
	B									
	C	17	n			110	125	91-149	1.1	3
	D	18	n			110		77-91	1.3	3
	E	M6	n*							
13				640	1.00					
	A	51	n			70	180	123-189	1	3
	B									
	C	19	n			200		197-225	1	3
	D	JPL				50		73-166	1	3
	E	M5	n*					73-166	1	*
14				652	.54					
	A	J15	pn			550	565	530-550	13.7-17.9	3
	B									
	C	52	n			140	220	158-254	2.2	3
	D	J12	pn			530	560	546-538	14.5-16.9	3
	E	J28	pn			535	540	526	13.5	*
15				652	.60					
	A	J14	pn				580	506-532	13.9-16.3	3
	B									
	C	53	n				70	134-296	1	3
	D	J13	pn			550		428-476	10.9-13.2	3
	E	J27	pn*				240	538-544	13.1-13.3	*

Page 4 - Table 1 Cont'd.

Run	Position	ASEC #	Type	m-Si Deposition		Photovoltage (mV)		ASEC Control Cells		
				Temperature (°C)	Thickness (kc)	Prehydro-generation	Posthydro-generation	Voc(mV) Range	Jsc(mA) Range	Lot No.
16				649	.43					
	A	J10	pn				562	528-546	16.4-16.5	3
	B									
	C	54	n			188	209	204-232	2.0	3
	D	J11	pn			561		508-528	14.1-16.9	3
	F	J27	pn*			550	540	338-544	13.1-13.3	*

*These samples had metal back contact before m-Si film deposition.

TABLE 2

SUMMARY OF RESULTS OF CONTROL P/N CELLS

(NO BSF, NO AR)

	Voc (mV)	Jsc (mA/cm^2)	CFF (%)	EFF (%)
AVERAGE	558	20.5	73	8.3
S.D.	$\pm$ 5	$\pm$0.5	$\pm$3	$\pm$.4
RANGE	546-562	19.7-21.2	67-76	7.4-8.8

TOTAL NO. OF CELLS = 12

VI. WORK PLANNED

- o $n\text{-}n^+$ and $p\text{-}n\text{-}n^+$ samples are being prepared.
- o p-Si wafers are being prepared to study the p-m-Si-p-Si structure for verification of the heterojunction concept (i.e. a voltage generated mainly by bandgap differences rather than by doping differences)..
- o The independent boron source (in graphite boat) is a potential carbon source. Instead of the present co-evaporation a highly boron doped Si source as the only evaporation source will be used.

VII. REFERENCES

1. P.H. Fang, L. Ephrath and W.B. Nowak, Appl. Phys. Lett. 25, 583 (1974).
2. J.I. Pankove, Appl. Phys. Lett. 32, 439 (1978).
3. P.H. Fang, C.C. Schubert, J.H. Kinnier and Dawen Pang, Appl. Phys. Lett. 39. 256 (1981).
4) Y. Nagarta, A. Kunioka and S. Yamazaki, Appl. Physa. Lett. 38, 142 (1981).
5) Y. Uchida, T. Ichimura, M. Ueno and M. Ohsawa, Proc. 9th Intern. Conf. Amorphous and Liquid Semiconductors (Grenoble, France 1981, B.K. Chakraverty and D. Kaplan, Eds.) p. C4-265.
6) R.A. Forman, W.R. Thurber and D.E. Aspness, Solid State Comm. 14, 1007 (1974).
7) Z. Iqbal, A.P. Webb and S. Veprek, Appl. Phys. Lett. 36, 163 (1980).
8) R. Richter and L. Ley, J. Appl. Phys. 52, 7281 (1981).
9) P.H. Fang, C.C. Schubert, Peiguang Bai and J.H. Kinnier, Appl. Phys. Lett. 41, 356 (1982).
10) A. Matsuda, K. Kumagai and K. Tanaka, Jpn. J.A.P. Letters 22, 34 (1983).
11) P.H. Fang, Peiguang Bai, C.C. Schubert and J.H. Kinnier, Jpn. J. Appl. Phys. (To appear.).

12) T. Hamasaki, H. Kurata, M. Hirose and Y. Osaka, Appl. PHys. Lett. 37, 1984 (1980).

13) J. Gonzalex-Hernandez and Raphael Tsu, Appl. Phys. Lett. 42, 90 (1983).

14) H. Richter and L. Ley, J. Physique, Coll. C1, Suppl. 10, 43, 247 (1982).

15) J.C. Knights, G. Lucovsky and R.I. Nemanick, J. Non-Crys. Solids, 32, 393 (1979).

16) A Matsuda, T. Yoshida, S. Yamaskai and K. Tanaka, Jpn. J. Appl. Phys. 20 L183 (1981).

17) Y. Mishima, S. Miyazaki, M. Hirose and Y. Osaka, Phil. Mag. B46, 1 (1982).

18) Y. Uchida, T. Ichimura, M. Ueno and H. Haruki, Jpn. J. Appl. Phys. Lett. 21, 586 1982.

19) H. Sakai, M. Kamiyaya, M. Ueno, K. Yamuda and Y. Uchida, SPIE-Int. Soc. Opt. Eng. Tech. Symp. East 183 (Arlington, VA, April 5-6, 1983).

APPENDIX I

INDIVIDUAL CELL DATA

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: M.S. / C.S. · 1st Lot

TEST CONDITION: AM1

TEMPERATURE: 28°

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
3-1	605	~~14.1~~				
3-2	5	13.1				
~~3-3~~	7	15.6				
3-4	8	14.7				
3-5	15	18.3				
3-6	16	16.4				
3-7	26	18.6				
3-8	23	16.7				
4-1	38	16.9				
4-2	39	18.4				
4-3	92	18.1				
4-4	94	19.3				
4-5	92	18.0				
4-6	107	19.1				
4-7	94	16.1				
4-8	103	17.3				
5-1	221	~~14.9~~				
5-2	203	~~16.4~~				

SOLAR CELL ELECTRICAL DATA

ELL DESCRIPTION: m-Si/c-Si . 1st Lot

EST CONDITION: AM1

EMPERATURE: 28°

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
5-3	19	14.0				
5-4	21	15.0				
5-5	3	7.6				
5-6	4	7.6				
5-7	3	9.6				
5-8	3	9.1				
6-1	2	3.7				
6-2	2	5.9				
6-3	2	2.6				
6-4	2	2.3				
6-5	1	4.1				
6-6	2	4.1				
6-7	2	8.1				
6-8	2	8.4				
32-1	8	1.3				
32-2	13	4.4				
32-3	4	3				
32-4	10	7.3				

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: 1st lot

TEST CONDITION:

TEMPERATURE:

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
32 5	3	4.4				
32 6	9	11.3				
32 7	1	1.4				
32 8	9	9.0				
33-1	25	14.1				
33 2	29	14.0				
33 3	24	14.9				
33-4	24	15.1				
33-5	17	14.9				
33-6	14	14.4				
33 7	21	12.4				
33 8	14	10.6				
34.1	2	3.9				
34 2	5	7.6				
34.3	2	4.7				
34.4	2	6.4				
34.5	2	5-3				
34.6	2	5.7				

SOLAR CELL ELECTRICAL DATA

LL DESCRIPTION: 1st Lot

ST CONDITION:

MPERATURE:

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
34-7	1-3	6.9				
34-8	1.6	7.6				
35-1	88	10.1				
35-2	94	14.9				
35-3	95	11.1				
35-4	110	15-7				
35-5	103	7.6				
35-6	117	14.7				
31-1	108	9.3				
75-0	57	6.1				
36-1	4	11.1				
36-2	4	9.3				
36-3	8	10.9				
36-4	6	6.9				
36-5	6	11.3				
36-6	6	8.9				
36-7	5	11.1				
36-8	4	10.9				

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: m-Si 2nd l.t

TEST CONDITION: AM1 no AR
TEMPERATURE: 28°C

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
7-1	20	8.6				
7-2	40	12.5				
7-3	140	13.3		35	0.7	
7-4	202	13.0		32	0.8	
8-1	344	14.3		37	1.8	
8-2	390	14.3		39	2.2	
8-3	426	14.3		46	2.8	
8-4	340	14.3		32	1.6	
9-1	20	8.8				
9-2	20	8.3				
9-3	20	11.9				
9.4	60	14.1				
12-1	314	14.3		35	1.6	
12-2	86	14.8		30	0.2	
12-3	200	14.7		29	0.8	
12-4	374	15.1		35	2.0	
13.1	146	12.7		22	0.4	
13.2	114	10.4		21	0.2	
13.3	148	12.6		23	0.4	
13.4	216	14.1		23	0.7	

SOLAR CELL ELECTRICAL DATA

LL DESCRIPTION: mid lot

ST CONDITION:

MPERATURE:

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	n %	AREA cm^2
141	60	17.4		22	0.2	
142	60	17.7		24	0.3	
143	80	17.6		27	0.4	
144	84	17.2		35	0.5	
381	242	12.9		32	1.0	
383	344	13.1		38	1.7	
384	198	13.1		29	0.8	
391	430	12.7		35	1.9	
392	460	13.3		44	2.7	
393	378	12.9		39	1.9	
394	254	9.8		26	0.7	
401	414	12.6		34	1.8	
402	470	12.8		42	2.5	
403	452	12.8		39	2.2	
404	482	12.9		49	3.0	
441	40	2.0				
442	60	4.1				
443	40	7.1				
444	106	7.4		23	0.4	
371	286	13.9		36	1.5	

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: 2nd lot.

TEST CONDITION:
TEMPERATURE:

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	η %	AREA cm^2
372	298	14.1		40	1.7	
373	210	14.1		33	1.0	
374	244	14.1		37	1.3	
441	40	2.4				
442	60	5.2				
443	40	8.3				
444	110	8.4		22	0.2	
451	20	0.8				
452	40	3.5				
453	282	13.7		27	1.0	
454	414	14.3		38	2.3	
461	116	8.2		21	0.2	
462	98	6.8		21	0.1	
463	80	4.6				
464	20	0.9				

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: m-Si on n-c-Si. 3rd lot.

TEST CONDITION: AM1 no AR
TEMPERATURE: 28C

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	η	AREA
	mV	mA/cm^2	mW	%	%	cm^2
10-1	402	15.1		54	3.3	
10-2	418	14.8		61	3.8	
10-3	428	14.9		62	3.9	
10-4	408	14.9		56	3.4	
11-1	322	13.7		54	2.4	
11-2	344	14.5		54	2.7	
11-3	356	14.7		57	3.0	
11-4	356	11.7		45	1.9	
15-1	201	1.5				
15-2	214	1.7				
15-3	216	1.4				
16-1	182	7.9		22	0.3	
16-2	160	6.7		19	0.2	
16-3	140	3.7		20	0.1	
16-4	144	1.8		31	0.1	

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: m-Si/esi 3rd Lot

TEST CONDITION:

TEMPERATURE:

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
17-1	91	0.5				
17-2	115	0.4				
17-3	137	0.6				
17-4	149	1.1				
18-1	82	1.1				
18-2	91	1.3				
18-3	91	0.5				
18-4	77	1.0				
19-1	197	0.4				
19-2	219	0.4				
19-3	207	0.3				
19-4	225	0.3				
43-1	390	14.5		51	2.9	
43-2	388	14.5		50	2.8	
43-3	376	14.5		47	2.5	
43-4	410	14.7		51	3.1	

SOLAR CELL ELECTRICAL DATA

ELL DESCRIPTION: mc-Si/c-Si 3rd lot

EST CONDITION:

EMPERATURE:

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
49-1	121	0.5				
49-2	154	0.6				
49-3	125	0.8				
49-4	126	0.7				
51-1	179	0.2				
51-2	180	0.2				
51-3	168	0.2				
51-4	123	0.1				
50-1	20	0				
50-2	—	0				
50-3	106	0.2				
50-4	161	0.2				
52-1	254	2.2				
52-2	226	0.6				
52-3	158	—				

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: mSi / c-Si . 3rd lot

TEST CONDITION:

TEMPERATURE:

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
53-1	134	0.9				
53-2	200	0.4				
53-3	274	0.8				
53-4	296	0.7				
54-1	204	0.2				
54-2	232	.1-.2				
54-3	206	2.0				
54-4	204	1.1				

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: mSi / P-n c-Si . 3rd lot

TEST CONDITION: AM1 no AR

TEMPERATURE: 28°C

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	n %	AREA cm^2
J10-1	540	16.2		28	2.5	
J10-2	546	16.5		29	2.6	
J10-3	544	16.2		28	2.5	
J10-4	528	16.1		29	2.5	
J11-1	514	16.7		37	3.2	
J11-2	522	16.9		35	3.1	
J11-3	528	16.7		36	3.2	
J11-4	508	14.1		27	1.9	
J12-1	528	16.1		36	3.1	
J12-2	526	14.5		29	2.2	
J12-3	538	16.9		30	2.7	
J13-1	476	13.2		27	1.7	
J13-2	438	10.0		25	1.1	
J13-3	428	11.4		26	1.3	
J13-4	428	12.2		26	1.3	

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: mSi/c-n junction · 3rd lot

TEST CONDITION:

TEMPERATURE:

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
J14-1	506	16.2		32	2.6	
J14-2	530	16.3		31	2.7	
J14-3	532	13.9		28	1.7	
J15-1	550	16.8		34	3.2	
J15-2	546	17.0		44	4.1	
J15-3	530	13.7		27	1.9	
J15-4	532	16.3		29	2.5	

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: JPL Samples m-Si / c-Si 3rd lot

TEST CONDITION:

TEMPERATURE:

NO.	V_{OC}	J_{SC}	P_{Max}	CFF	n	AREA
	mV	mA/cm^2	mW	%	%	cm^2
9C-1	260	1.3				
9C-2	275	1.8				
9C-3	272	1.7				
9C-4	235	1.1				
10A1	256	0.8				
10A2	281	0.5				
10A3	78	0.4				
10A4	305	0.7				
13D1	166	0.1				
13D2	90	0				
13D3	104	0				
13D4	73	0				

SOLAR CELL ELECTRICAL DATA

ORIGINAL PAGE IS OF POOR QUALITY

CELL DESCRIPTION: (metal back) . ~~Texture~~ ~~wafer~~ mSi/p-n 2D

TEST CONDITION: AM1

TEMPERATURE: 28°C

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	n %	AREA cm^2
J26-1	544	12.9		70	4.9	
J-26-2	544	12.8		71	4.9	
J26-3	546	12-7		74	5.1	
J26-4	544	12.9		72	5.1	
J27-1	544	13.2		71	5.1	
J27-2	538	13.3		61	4.3	
J27-3	542	13.1		68	4.9	
J27-4	542	13.1		64	4.5	
J28-1	526	13.5		56	3.9	

SOLAR CELL ELECTRICAL DATA

CELL DESCRIPTION: mesh back mis: [illegible] s.

TEST CONDITION: AM1

TEMPERATURE: 28°

NO.	V_{OC} mV	J_{SC} mA/cm^2	P_{Max} mW	CFF %	n %	AREA cm^2
M71	92	2.4		29		
2	90	0.9		33		
3	80	0.6		26		
4	80	0.5		24		
M81	40	1.0		[illegible]		
2	80	1.0		30		
3	20	1.2		[illegible]		
4	20	0.8				

APPENDIX II

TIME SCHEDULE

TIME SCHEDULE